Slow slip prior to runaway slip in laboratory

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Earthquake nucleation and propagation involves the acceleration of slip on a fault from a background, quasi-static, low-velocity state towards meter-per-second values. Following e.g. Niemeijer & Spiers, [2007, JGR], Takahashi et al., [2017, G-cubed] recently conducted shear experiments on brine-saturated simulated gouge composed of 80:20 wt.% mixtures of halite and muscovite at 5 MPa in normal stress and room-temperature and reported that the strength of the gouge shows the maximum at 1 mm/sec in the slip velocity. This boundary velocity of 1 micron/sec divides into velocity-strengthening regime controlled by pressure solution creep under low velocity condition and velocity-weakening regime characterized by cataclastic deformation, such as dilation, comminution and shear localization under high velocity condition. The mixtures of halite and muscovite could be a good analogue material to simulate the fault behaviors at around the brittle-ductile transition. Moreover, Takahashi et al., [2017] observed the direct effect disappears when the velocity exceeds another boundary velocity, V_c (~20 mm/sec). This means the fault slip easily accelerates towards "a runaway slip" once the velocity exceeds V_c. Therefore, to measure these boundary velocities in nature is very importance to understand the earthquake nucleation and propagation processes.

Takahashi et al., [2017] evoked a question, thus --- How does the fault at around brittle-ductile transition respond against a perturbation of the stress? Generally, in recognizing the fault slip stability, we use a sign of the velocity dependence of frictional strength, *so-called* a-b, under velocity-controlling boundary condition experiments. However, as long as we are adopting the velocity-controlling boundary condition experiments, spontaneous behavior of slip acceleration/decoration won't be observable. Shear stress step change tests will be required to observe spontaneous evolution of the slip velocity. Excess stress over the maximum strength will be expected to induce unstable and runaway slip. On the other hand, at relatively low-velocity state, pressure solution creep will be expected to play a role to suppress the slip acceleration. Therefore, we have a potential to catch the fault behaviors of both slow slip and runaway slip in laboratory by adopting stress-controlling boundary condition experiments.

I performed rotary shear experiments with step changes in shear stress on the brine-saturated, 80:20 (wt %) mixture of halite (grain size < 75 mm) and muscovite (grain size < 30 mm) gouge. Approximately 1.65 g of the mixed gouge was then sandwiched between two teethed steel piston rings, having a size of 38 mm in inner diameter and 50 mm in outer diameter, which formed a 1 mm thick layer initially. I use a high-velocity rotary shear apparatus settled at GSJ, which has been developed by Toshi Shimamoto [e.g., Togo and Shimamoto, 2012, JSG]. I modified this apparatus to enable a torque control with an accuracy of 0.002 in the friction coefficient at 5 MPa in the normal stress. I measured rotation displacement using a potentiometer set near the piston ring at a rotation side. I obtained well-reproducible relationship between steady-state friction coefficient and steady-state velocity, comparing with the results from both Takahashi et al., [2017] and Niemeijer and Spiers [2007].

We obtained slow slip behaviors, spontaneous acceleration followed by deceleration, when the stress was nearly equal to but lower than the maximum strength of the simulated gouge. Once the velocity excessed ≈1 mm /sec, the runaway slip occurred followed by dynamic weakening at V ≈Vc = 20 μm/sec. However, the shear stress was sustained for 2~3 hours before the dynamic weakening occurred, even after the velocity exceeded 1 mm /sec. This delay of the onset of dynamic weakening could be explained by that the simulated gouge earned strength temporary due to the direct effect.

Keywords: slow slip, pressure solution creep, direct effect